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An Evaluation of Emission Factors for Waste-to-Energy Systems

Monsanto Research Corp.
Dayton, OH

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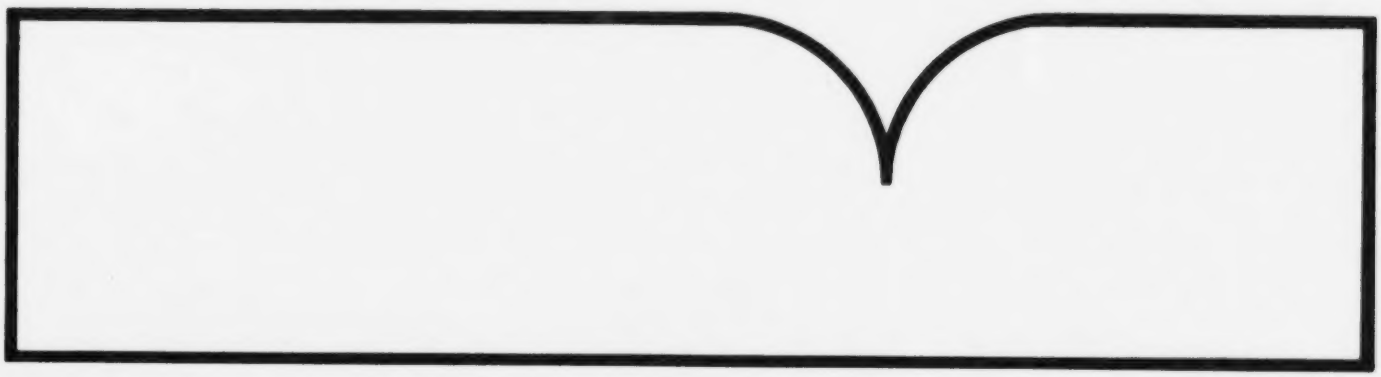

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An Evaluation of Emission Factors for Waste-to-Energy Systems

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The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology for stationary sources is available to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and the Resource Conservation and Recovery Act. The Fuels Technology Branch (FTB) of the IERL-Cincinnati has been assigned the responsibility for characterizing emissions from waste-to-energy systems. This report, prepared by Monsanto Research Corporation, is intended to supplement the document entitled "Compilation of Air Pollution Emission Factors" as a source of information concerning emission rates from solid waste combustion, since the latter does not incorporate the most recent technical data. Results presented herein will provide information to the EPA regional and program offices that is useful for decision-making regarding environmental research programs and the technological feasibility of compliance with existing or forthcoming regulations.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains a summary of emission factors for the combustion of refuse for the purpose of providing energy recovery or volume reduction. This study was conducted to provide an up-to-date compilation of these factors for use in planning and assessing the benefits and risks from this industry. Further information on this subject may be obtained from the Fuels Technology Branch, Energy Systems Environmental Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology for stationary sources is available to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and the Resource Conservation and Recovery Act. The Fuels Technology Branch (FTB) of the IERL-Cincinnati has been assigned the responsibility for characterizing emissions from waste-to-energy systems. This report, prepared by Monsanto Research Corporation, is intended to supplement the document entitled "Compilation of Air Pollution Emission Factors" (PB 275525) as a source of information concerning emission rates from solid waste combustion, since the latter does not incorporate the most recent technical data. Results presented herein will provide information to the EPA regional and program offices that is useful for decision-making regarding environmental research programs and the technological feasibility of compliance with existing or forthcoming regulations.

This report was submitted by Monsanto Research Corporation in partial fulfillment of Contract No. 68-03-2550 under the sponsorship of the U.S. Environmental Protection Agency. This project was performed during the period November 1978 to November 1979. Mr. Harry Freeman of the Fuels Technology Branch at IERL-Cincinnati served as Project Officer.

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SECTION 1

INTRODUCTION

Generalized estimates of the magnitude of air pollution problems due to industrial sources can be made using derived numerical values known as "emission factors." An emission factor relates the mass of material released to some measure of source capacity, for example, grams emitted per quantity of fuel burned for combustion units. Thus, emissions data obtained from source testing material balances, or engineering estimates can be reduced to numbers with a common basis for purposes of comparison. Such data, gathered for existing sources, can then be used to predict emission rates for systems either under development or under construction, indicating what air pollution control technology may be necessary to comply with applicable federal and state regulations.

Air pollutants generated by solid waste combustion include particulate matter and, in lesser amounts, hydrocarbons, oxides of nitrogen and sulfur, hydrogen chloride, polynuclear aromatic compounds, and trace elements. A literature search was conducted to generate emission factors from information compiled by other investigators. Results are presented herein for emissions of both criteria and noncriteria pollutants from selected categories of solid waste combustion.

SECTION 2

CLASSIFICATION OF SOLID WASTE COMBUSTION SYSTEMS

Solid wastes collected in cities and suburbs can be disposed of, under controlled conditions, in municipal incinerators. Historically, the sole intent of such processing has been reduction of the waste to a relatively small volume of odorless, inert residue prior to landfilling. Recently, depletion of supplies of conventional fuels, such as gas and oil, have made extraction of energy from refuse an increasingly attractive solid waste management option, adding another degree of complexity to incinerator design and operation. In order to examine the effects of the type of processing on air pollutant emissions, all solid waste combustion systems were classified into three categories as discussed below.

CATEGORY I

Category I is defined as mass-fired incineration for the sole purpose of volume reduction; this is the most simplified solid waste combustion technology. Raw waste, as received from collection vehicles and including glass bottles, ceramics, metal cans, and other noncombustible material, is fed directly from the storage pit to the incineration chamber. No attempt is made to recover the heat energy contained in the combustion off-gases before release to the atmosphere via a stack.

Incinerator technology for Category I, as well as for the other two categories, is as diverse as the communities which they are meant to serve. Figures 1 through 5 are schematic diagrams of Category I incinerators [1] for which particulate emissions data are given in Section 3. Incinerator A consists of a dual-chamber furnace with reciprocating grates followed by stationary grates; air pollution control is accomplished by impingement on wetted columns. Incinerator B, also a mutliple-chamber furnace using flooded baffle walls for particulate removal, is equipped with rocking grates. Incinerator D, another multiple-chamber

---

[1] Achinger, W. C., and L. E. Daniels. An Evaluation of Seven Incinerators. In: Proceedings of the 1970 National Incinerator Conference, American Society of Mechanical Engineers, Cincinnati, Ohio, May 17-20, 1970. pp. 32-64.

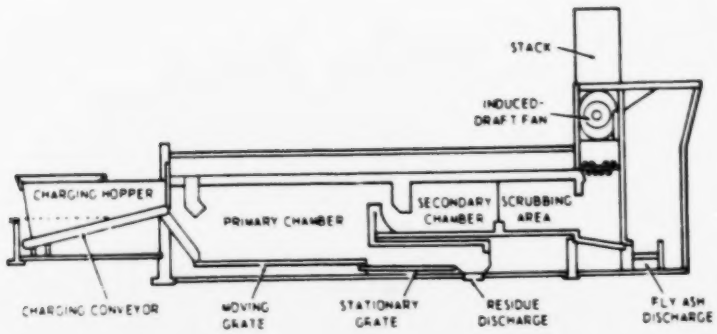


Figure 1. Schematic diagram of Category I incinerator A [1].

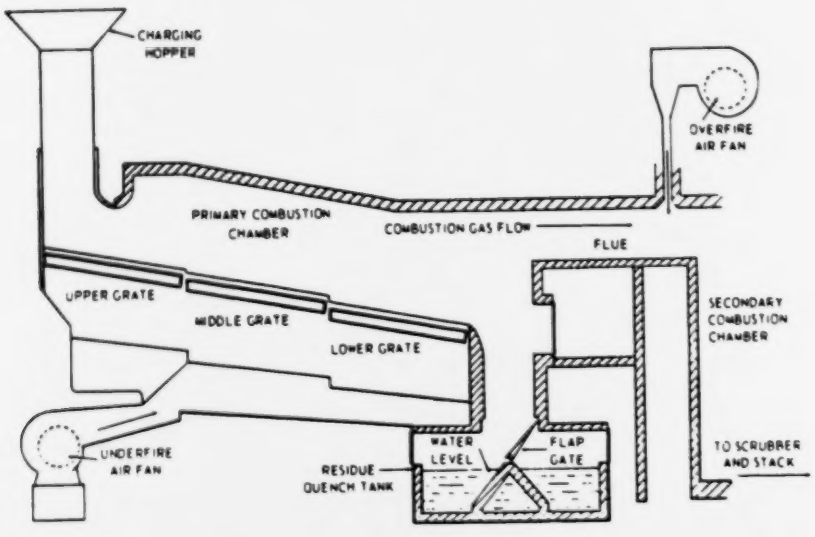


Figure 2. Schematic diagram of Category I incinerator B [1]

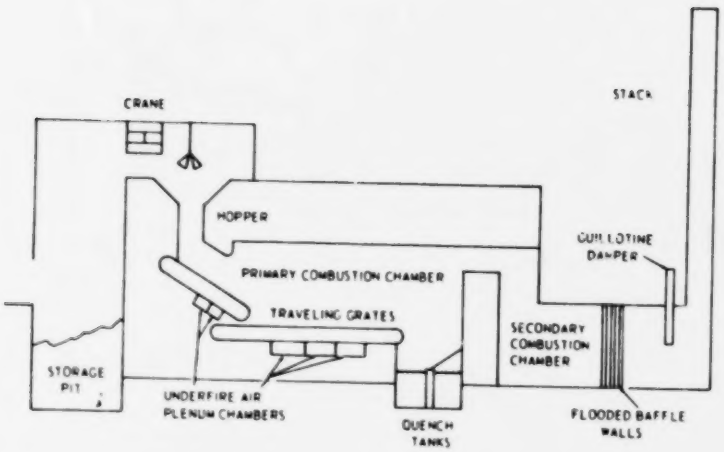


Figure 3. Schematic diagram of Category I incinerator D [1].

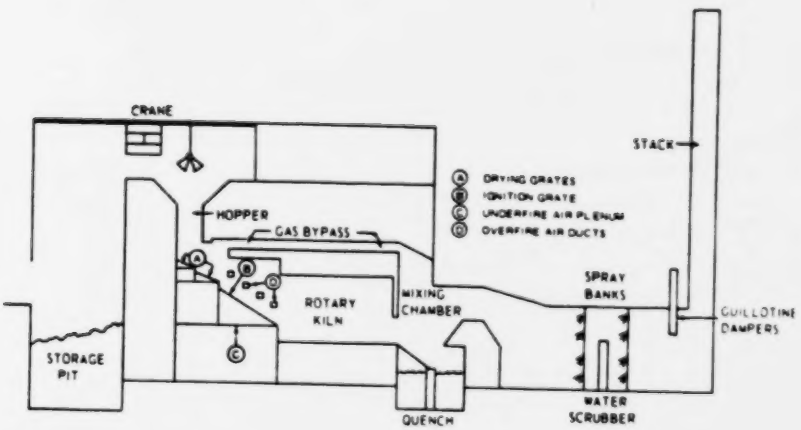


Figure 4. Schematic diagram of Category I incinerators E and F [1].

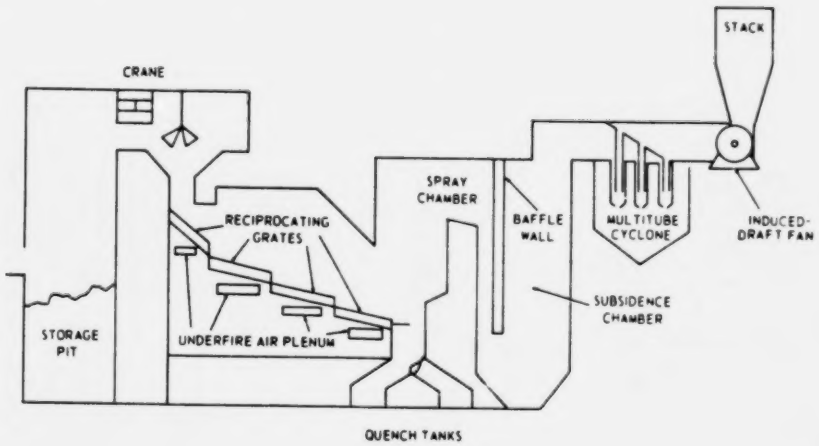


Figure 5. Schematic diagram of Category I incinerator G [1].

unit with flooded baffle walls, contains two sections of traveling grates, one horizontal and one inclined. A group of reciprocating grates followed by a rotary kiln make up the multiple-chamber design of Incinerators E and F, which use water sprays for pollution control. Incinerator G, the only single-chamber device, uses reciprocating grates to move refuse through the furnace; a multitube cyclone is employed to remove particulates from the stack gases.

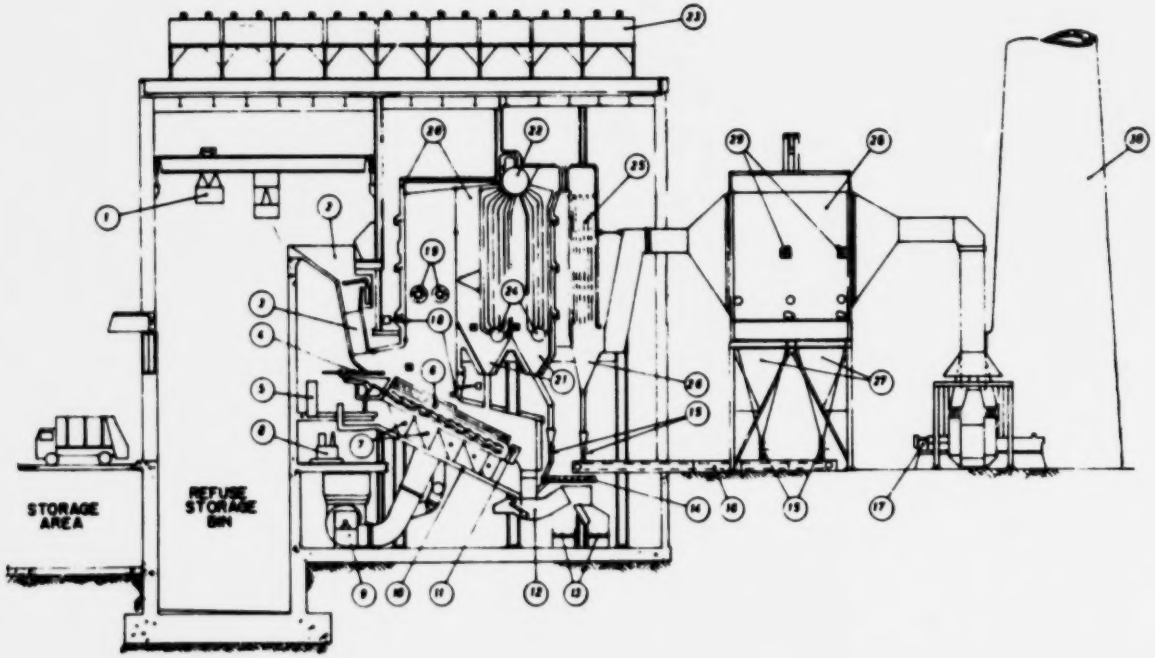
CATEGORY II

Unlike Category I, incinerators classified as Category II are waste-to-energy systems, since the latter accomplishes both volume reduction of refuse and utilization of generated heat for production of steam and/or electricity. Category I and II are similar in that both types of units use raw waste as feed material.

Figures 6 and 7 are examples of Category II incinerator design. The Chicago Northwest incinerator, depicted - Figure 6, is fed by a reverse reciprocating stoker and integrated with a welded waterwall boiler of multipass design [2]. An electrostatic

---

[2] Stabenow, G. Performances of the New Chicago Northwest Incinerator. In: Proceedings of the 1972 National Incinerator Conference, American Society of Mechanical Engineers, New York, New York, June 4-7, 1972. pp. 178-194.



LEGEND

1) Crane
2) Refuse Hopper
3) Refuse Chute
4) Refuse Feed
5) Stoker Control Panel
6) Reverse Reciprocating Stoker
7) Undergrate Air Plenum Chambers
8) Hydraulic Pump
9) Forced Draft Fan
10) Automatic Siftings
11) Clinker Roll
12) Residue Discharger
13) Residue Conveyer
14) Fly-Ash Conditioning Screw
15) Rotary Valves for Fly Ash Discharger
16) Fly Ash Flight Conveyer
17) Induced Draft Fan
18) Overfire Air Nozzles
19) Auxiliary Burners. (100% capacity)
20) Radiant Waterwalls. (Welded Panel Construction)
21) Boiler Fly Ash Hoppers
22) Steam Drums
23) Steam Condensers
24) Bottom Boiler Drums
25) Economizer
26) Economizer Fly Ash Hopper
27) Fly-Ash Hoppers for Electrostatic Precipitators
28) Electrostatic Precipitators
29) Rappers for Fly-Ash Collector Plates
30) Chimney

Figure 6. Cross-sectional view of the Chicago Northwest Incinerator [2].

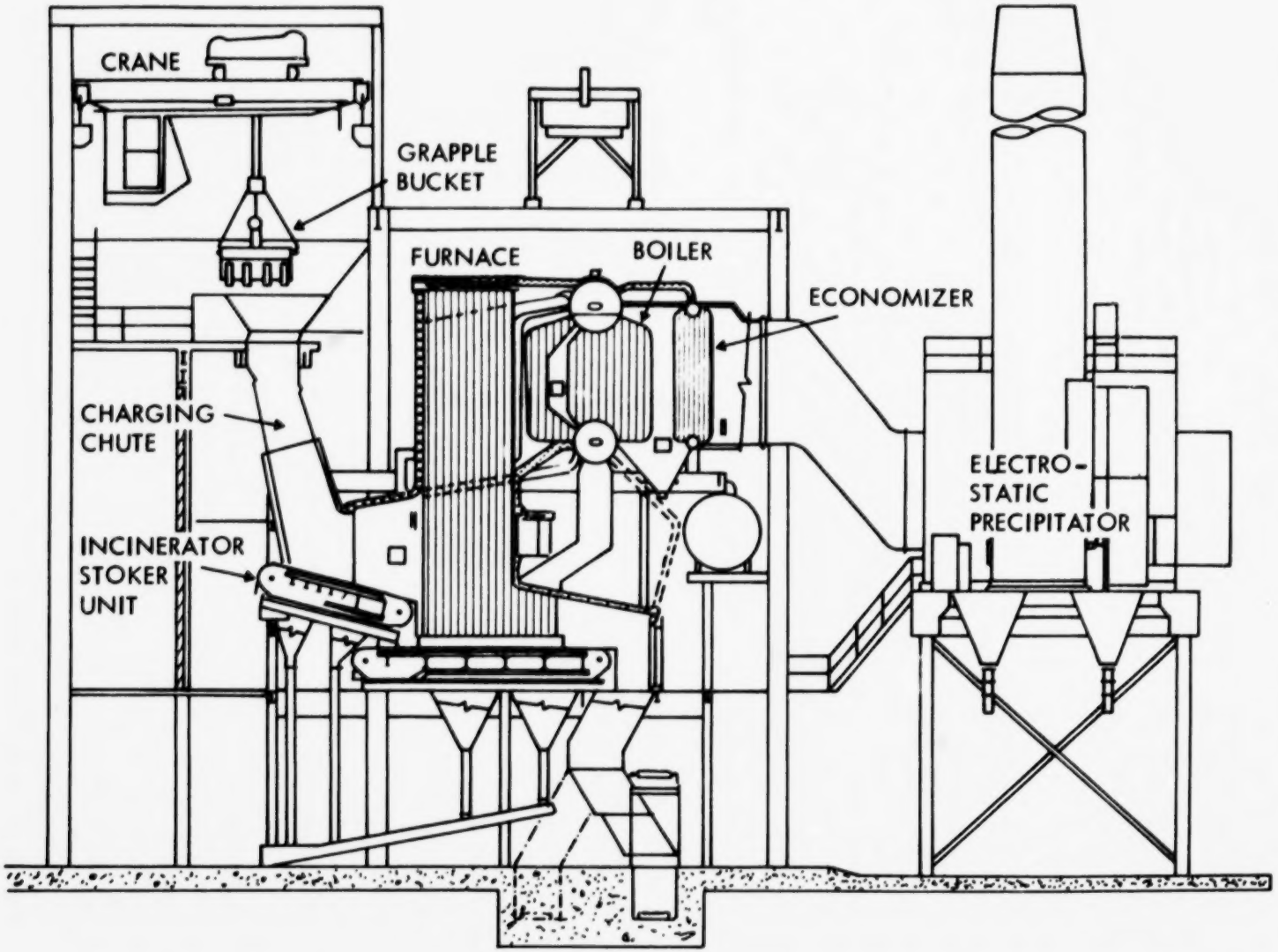


Figure 7. Cross-sectional view of the Braintree Municipal Incinerator [3].

precipitator is used for removal of particulates, including low-density paper char. The two incinerators of the Braintree, Massachusetts facility, both equipped with electrostatic precipitators for air pollution control, are traveling-grate, waterwall systems designed for mass-firing of unprocessed mixed municipal refuse [3]. After passing through the electrostatic precipitators, the boiler flue gases are discharged through a stack common to both control devices.

CATEGORY III

Category III boilers are similar to Category II units in that both recover heat energy from combustion of solid waste. However, in Category III systems, prior to being charged to the furnace, raw refuse is upgraded in heating value by either selective removal of noncombustible material, or addition of fossil fuel, that is, coal, gas, or oil. Solid waste processing may include salvage of salable noncombustible components such as furniture, stoves, or refrigerators; shearing or shredding oversize material; magnetic separation for ferrous metal recovery; air classification for removal of glass and other heavy rejects; and recovery of nonferrous metals. Not all Category III facilities will employ all of the above solids handling techniques.

Figure 8 is a cross-sectional view of one of two spreader-stoker, traveling-grate boilers at the City of Ames (Iowa) Municipal Power Plant [4]. This installation, which commenced operation on August 30, 1975, was the first continuous full-scale system for the processing of municipal solid waste as a supplementary fuel for power generation, i.e., Category III as defined in this report. The processing plant at Ames incorporates two stages of shredding, ferrous and nonferrous metal recovery, and air classification of raw waste prior to mixing with coal to yield refuse-derived fuel (RDF). Multiple

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[3] Golembiewski, M., K. Anath, G. Trishcan, and E. Baladi. Environmental Assessment of A Waste-to-Energy Process: Braintree Municipal Incinerator (Revised Final Report). Contract No. 68-02-2166, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1979. 207 pp.

[4] Hall, J. L., A. W. Joensen, D. Van Meter, R. Wehage, H. R. Shanks, D. E. Fiscus, and R. W. White. Evaluation of the Ames Solid Waste Recovery System, Part III. Environmental Emissions of the Stoker-Fired Steam Generators. EPS Grant No. R803903-01-0 and ERDA Contract No. W-7405 ENG-82. U.S. Environmental Protection Agency, Cincinnati, Ohio, and Energy Research and Development Administration, Washington, D.C., 1977. 774 pp.

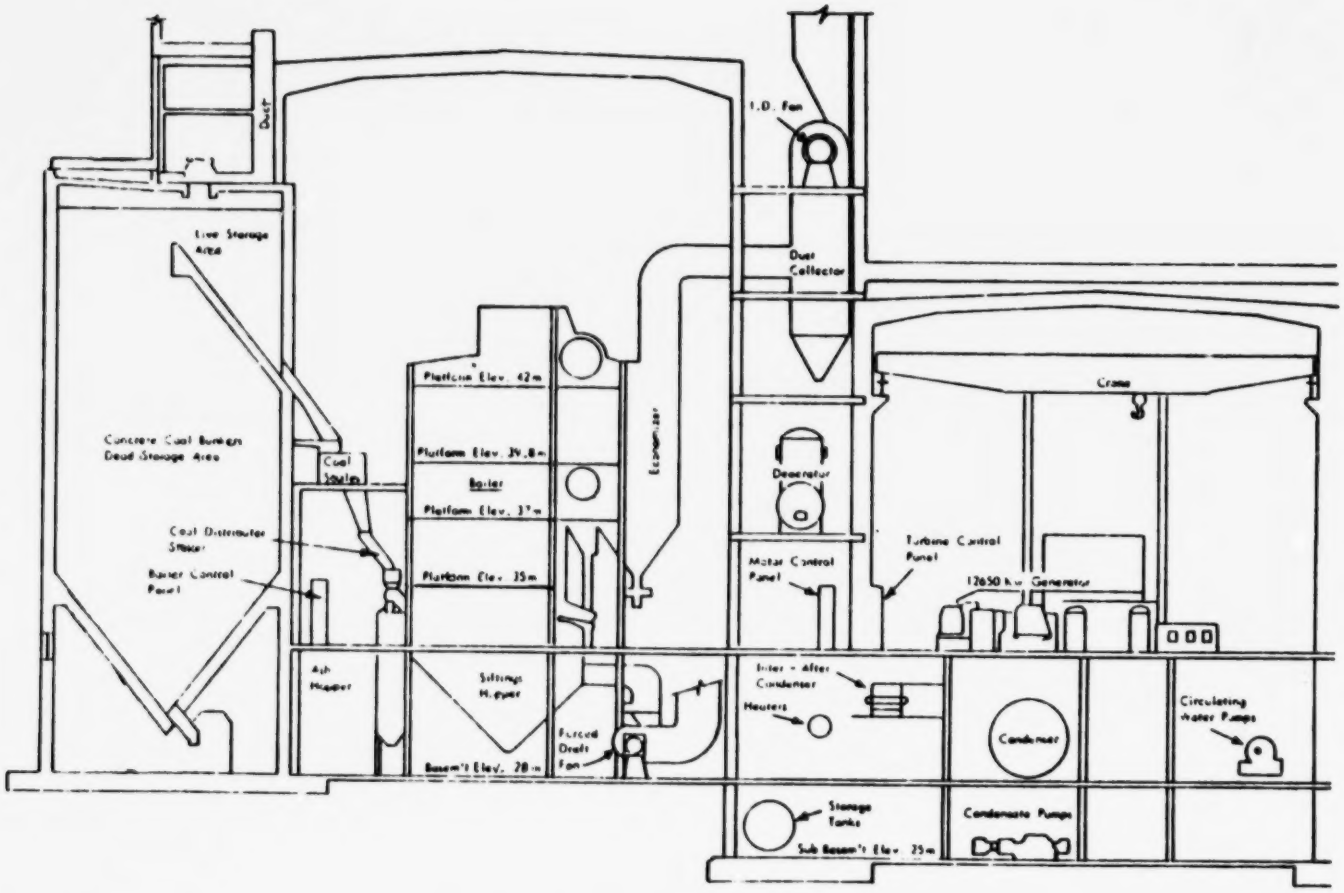

Figure 8. Cross-sectional view of the Ames Municipal Incinerator [4].

cyclone collectors are used for particulate removal from the exhaust gas from both boilers. The Ames Solid Waste Recovery System has been the subject of a comprehensive investigation of the environmental effects of the use of solid waste as a fuel supplement. The work has been sponsored by both the EPA and the Energy Research and Development Administration [4]. The results of that study are reported herein in the appropriate segments of Sections 3 and 4.

SECTION 3

EMISSIONS OF CRITERIA POLLUTANTS

PARTICULATES

Particulate emissions from combustion sources consist of particles of mineral matter and sometimes contain unburned combustible material. For this reason, earlier investigators of the environmental impact of incineration had speculated that the amount of particulate emissions could be related to the composition of the feed material, that is, the combustible fraction and/or ash content of that fraction. Data on these two feed characteristics for all three categories defined in Section 2, as well as coal, are reported in Tables 1 through 3 and summarized in Table 4.

In general, the combustible fraction of municipal solid waste consists of food waste; garden waste; paper products; plastic, rubber, and leather; textiles; and wood. The noncombustible material includes metals; glass and ceramics; and ash, rocks, and dirt. All the material for Category III is considered to be combustible because preprocessing techniques such as shredding, air classifying, screening, and magnetic separation of ferrous metals are usually practiced prior to feeding. Coal, consumed in Category III boilers when a refuse mixture is not fed, is assumed to be 100% combustible since it does not contain bulk metals, glass, ceramics, rocks, or dirt.

The reported ash contents for Categories I and II differ only because of the specific data sources used in compiling Table 1. In general, average ash contents for these categories would be expected to be the same. However, the ash content of coal is typically greater than that of the combustible fraction of refuse, hence the difference between Category III and Categories I and II.

TABLE 1. COMBUSTIBLE FRACTIONS AND ASH CONTENTS OF CATEGORY I FEED MATERIAL [1] (Percent by weight, dry basis)

Incinerator	Combustible fraction of feed material	Ash content of combustible fraction
A	80.9	8.3
B	80.3	5.7
D	82.6	10.8
E	77.7	1.6
F	85.7	3.6
G	75.5	5.9

TABLE 2. COMBUSTIBLE FRACTIONS AND ASH CONTENTS OF CATEGORY II FEED MATERIAL [2, 3, 5] (Percent by weight, dry basis)

Incinerator	Combustible fraction of feed material	Ash content of combustible fraction
Braintree		
Test No. 1 (1/17/78)	81.6	2.53
Test No. 2 (1/18/78)	80.1	4.25
Test No. 3 (1/19/78)	79.1	7.09
Chicago Northwest	66.8	3.5

[5] Reed, J. C., J. D. Cobb, and J. C. Ting. Environmental Assessment of Combustion Processes for Industrial-Municipal Symbiosis in Refuse Disposal. In: Proceedings, AIChE/EPA Third National Conference on Water Reuse. pp. 337-344.

TABLE 3. ASH CONTENTS OF CATEGORY III FEED MATERIAL [4, 6][a]
(Percent by weight, dry basis)

Incinerator	Feed material[b]	Ash Content
Ames, Iowa	80% Iowa coal/20% RDF	18.8
	50% Iowa coal/50% RDF	17.1
	80% Iowa-Wyoming coals/20% RDF	12.7
	50% Iowa-Wyoming coals/50% RDF	13.9
	Iowa coal	20.2
	Iowa-Wyoming coals	11.7

[a]All preprocessed Category III feed material and coal are assumed to be 100% combustible for the purposes of this study.

[b]RDF = refuse-derived fuel; feed mixtures of RDF and coal are described in percentage of total heat energy input.

TABLE 4. SUMMARY OF COMBUSTIBLE FRACTIONS AND ASH CONTENTS OF INCINERATOR FEED MATERIAL
(Percent by weight, dry basis)

Category	Combustible fraction of feed material	Ash content of combustible fraction
I	75.5 - 85.7	1.6 - 10.8
II	66.8 - 81.6	2.5 - 7.1
III	100	12.7 - 18.8
Coal	100	11.7 - 20.2

[6] Hall, J. L., H. R. Shanks, A. W. Joensen, D. B. Van Meter, and G. A. Severens. Emission Characteristics of Burning Refuse-Derived Fuel with Coal in Stoker-Fired Boilers. (Paper presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Texas, June 25-30, 1978.) 16 pp.

Tables 5 through 8 provide data on uncontrolled particulate emissions for the three categories and coal combustion in a Category III boiler. The emission factors are given in four types of units, as follows:

1) grams of particulate per kilogram of combustible material fed (g/kg);

2) pounds of particulate per ton of combustible material fed (lb/ton);

3) grams of particulate per kilogram of combustible material fed, all divided by the ash content of the combustible fraction (g/kg/% A);

4) Pounds of particulate per tone of combustible material fed, all divided by the ash content of the combustible fraction (lb/ton/% A).

TABLE 5. EMISSION FACTORS FOR UNCONTROLLED PARTICULATES FROM CATEGORY I [1]

Incinerator	Particulate emission factors[a,b]			
	g/kg	lb/ton	g/kg/% A	lb/ton/% A
A	16	32	1.9	3.9
B	23	45	4.0	7.9
D	13	27	1.2	2.5
E	11	22	7.0	14
F	15	29	4.0	8.0
G	27	54	4.6	9.2
Average	17	35	3.8	7.6

[a] Based on mass of combustible feed material.

[b] Calculations based on assumed control efficiencies of 60% for flooded baffle walls and 50% for water sprays or dry cyclones [7].

[7] Compilation of Air Pollutant Emission Factors, Third Edition. AP-42 (PB 275 525), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1977. 511 pp.

TABLE 6. EMISSION FACTORS FOR UNCONTROLLED PARTICULATES FROM CATEGORY II [2, 3, 5]

Incinerator	Particulate emission factors[a]			
	g/kg	lb/ton	g/kg/% A	lb/ton/% A
Braintree				
Test No. 1	7.1	14	2.8	5.6
Test No. 2	6.9	14	1.6	3.2
Test No. 3	9.0	18	1.4	2.7
Chicago Northwest				
Test No. PD-2	9.5	19	2.7	5.4
Test No. PD-3	23	45	6.4	13
Test No. PD-4	21	43	6.1	12
Test No. 1	21	42	5.9	12
Test No. 2	19	37	5.3	11
Average	14	29	4.0	8.0

[a]Based on mass of combustible feed material.

TABLE 7. EMISSION FACTORS FOR UNCONTROLLED PARTICULATES FROM CATEGORY III [4, 6]

Feed material	Load factor, %	Particulate emission factors[a,b]			
		g/kg	lb/ton	g/kg/% A	lb/ton/% A
80% Iowa coal/20% RDF	100	43	85	2.3	4.5
	80	80	159	4.2	8.5
	60	85	171	4.5	9.1
50% Iowa coal/50% RDF	100	52	103	3.0	6.0
	80	57	113	3.3	6.6
	60	58	116	3.4	6.8
80% Iowa-Wyoming coals/ 20% RDF	80	75	149	5.9	12
		69	137	5.4	11
	60	73	145	5.7	11
50% Iowa-Wyoming coals/ 50% RDF	80	70	141	5.1	10
		74	147	5.3	11
		65	130	4.7	9.4
	60	72	144	5.2	10
Average	--	67	134	4.5	9.0

[a]Data represent various operating conditions for Ames (Iowa) Solid Waste Recovery System.

[b]Calculations based on the determination that 100% of the feed material for Category III is combustible.

TABLE 8. EMISSION FACTORS FOR UNCONTROLLED PARTICULATES FROM COAL COMBUSTION [4, 6]

Feed material	Load factor, %	Particulate emission factors[a,b]			
		g/kg	lb/ton	g/kg/% A	lb/ton/% A
Iowa coal	100	90	179	4.4	8.9
	80	79	157	3.9	7.8
	60	70	140	3.5	6.9
Iowa-Wyoming coals	80	71	142	6.0	12
		55	111	4.7	9.5
		40	80	3.3	6.6
	60	44	89	3.8	7.6
Average	--	64	128	4.2	8.4

[a] Data are for combustion of coal in the Ames boilers, suited to cofiring of coal and refuse-derived fuel.

[b] Calculations based on the determination that coal is 100% combustible.

One of the most significant findings of this study is that emission factors for uncontrolled particulates from Categories I, II, and III and from coal combustion are essentially the same when reported on a normalized basis, that is, mass emitted per mass of combustible material fed, divided by the ash content of the combustible fraction. As shown in Tables 5 through 8, the average particulate emission factors for Categories I, II, and III and coal combustion are 3.8, 4.0, 4.5, and 4.2 g/kg/% A, respectively. This is a very small range of values considering the variations in incinerator design, feed materials, and operating conditions for the systems described herein. For instance, the six Category I incinerators described in Section 2 incorporate different grate types (i.e., reciprocating, rocking, and traveling), but this element of design does not have a significant influence on normalized emission factors, according to Table 5. The normalized particulate emission factor for Incinerator G, the only single-chamber unit among those in Category I, lies within the extremes defined by the multiple-chamber systems. Another pertinent conclusion regarding uncontrolled particulate emissions is that those from Category III (Table 7) exhibited no clear trend as a function of either percent of heat input in the form of refuse or boiler load factor.

Table 9 presents emission factors for uncontrolled particulates from Categories I, II, and III and coal combustion which were calculated by dividing the mass of emissions by the mass of total feed material. This data is provided for information purposes since many of the emission factors directly reported in the literature are in these units, or there may be insufficient characterization of the source to calculate emission factors on the basis of Tables 5 through 8 of this report. The numbers in Table 9 for Category III and coal combustion are identical to those in Tables 7 and 8, respectively, because all the feed material is combustible. However, Table 9 differs significantly from Tables 5 through 8 in that there is no apparent correlation among the emission factors for the various categories.

TABLE 9. EMISSION FACTORS FOR UNCONTROLLED PARTICULATES BASED ON TOTAL FEED MATERIAL [1-6]

Category	Average		Range	
	g/kg	lb/ton	g/kg	lb/ton
I	17	35	11 - 27	22 - 54
II	14	29	6.9 - 23	14 - 45
III	67	134	43 - 85	85 - 171
Coal	64	128	40 - 90	80 - 179

Applicable Particulate Control Technology

Emission control equipment now used on incinerators has been designed primarily to remove particulates because that is the only criteria pollutant currently regulated by federal and state standards. Technologically feasible methods for particulate control include mechanical collection (by cyclones), wet scrubbing, and electrostatic precipitation.

Dry cyclones are systems which create organized vortex motion within a particulate collector [8]. These devices therefore provide the force necessary to propel particles from the collector to a deposit hopper. Cyclone configurations are: (a) small diameter multiple systems (<12 in.), (b) larger diameter (18 in. and greater) multiple systems, and (c) single or double units with a diameter of 4 ft or more [8]. Generally, the efficiency of a

[8] Spaite, P. W. and J. O. Burckle, Selection, Evaluation and Application of Control Devices, Chapter 2, pp. 46-47; and S. Oglesby and G. B. Nichols, Electrostatic Precipitation, Chapter 5, pp. 191-193. In: Air Pollution, Third Edition, Volume IV, A. Stern, ed. Academic Press, New York, New York, 1977.

dry cyclone system is determined by the size of the cyclone configuration (the smaller configurations have greater efficiency), stack flow rate, and particle concentration, size and density. Only under ideal operating conditions can a dry cyclone attain a particulate control efficiency of 80 percent when applied to an incinerator.

Wet scrubbing systems would introduce liquid into collector to control particulate emissions from the incineration. The liquid usually serves to either chemically react with or dissolve particulate contaminants [8]. The first two wet-scrubbing control systems listed in Table 10 are of the low-energy type, hence the low collection efficiencies. A wetted baffle system consists of one or more vertical plates that are flushed by water spray. A settling chamber is simply a large refractory-lined chamber wherein gravitational settling of coarse particulates occurs as the incinerator exhaust gas velocity is reduced. Spraying the walls and bottom of the chamber with water inhibits re-entrainment of collected particulates. The high pressure drops required for venturi scrubbing may make its operating costs noncompetitive relative to those for electrostatic precipitation.

TABLE 10. COLLECTION EFFICIENCIES OF CONTROL SYSTEMS FOR PARTICULATE EMISSIONS FROM MUNICIPAL INCINERATION

Control system	Efficiency, %
Mechanical collection (cyclones)	30 - 80
Wet scrubbing	
Wetted baffles	10 - 60
Settling chamber and water spray	30 - 60
Venturi scrubber	90 - 99+
Electrostatic precipitation	90 - 99+

Electrostatic precipitation is the removal of dust or liquid aerosol from a gas stream by utilizing forces from electric charges in electric fields [8] The process usually involves particle charging by attachment of charges produced by an electrical corona in field provided, in most cases, by application of high direct-current voltages to dual electrodes. The particles are then removed by simple mechanical means, such as rapping or irrigation of collection electrodes with water. Electrostatic precipitation is one of the most effective demonstrated techniques for control of particulate emissions from

incineration. However, relative to other applications of electrostatic precipitation, removal efficiencies are limited because refuse incineration yields large volumes of gas containing particles of widely variable size and resistivity characteristics. In at least one case, mechanical difficulties with operation of an incinerator and its related support systems resulted in abnormally high particulate loadings, which consequently caused an electrostatic precipitator to function well below its design efficiency. Typical collection efficiencies for electrostatic precipitation and the other two techniques discussed above as applied to municipal incineration are given in Table 10.

Experience with Particulate Control Technology

Table 11 presents particulate emission data for several solid waste incinerators with differing emission control equipment. Calculations are based on standard conditions (70°F, 29.92 in. Hg, 12% CO_2). Particulate emissions are expressed in grams per dry standard cubic foot, in pounds per 1,000 lb of feed at 50% excess air, and in pounds per hour. The data reflect design, operational status, and efficiency of control systems at each incinerator site.

TABLE 11. COMPARATIVE PARTICULATE CONTROL AND EMISSION DATA FOR SELECTED INCINERATORS [1-3]

Incinerators	Control mechanism	Particulate emissions		
		gr/dscf	lb/1,000 lb @ 50% air	lb/hr
A	Wet scrubber	0.55	1.06	122
B	Wet scrubber: flooded baffle walls	1.12	-[a]	186
D	Wet scrubber: flooded baffle walls	0.46	0.85	173
E	Wet scrubber: water sprays; baffle walls	0.73	1.19	238
F	Wet scrubber: water sprays; baffle walls	0.72	1.18	-
G	Dry cyclones	1.35	2.70	386
Chicago, NW Test PD-2	Electrostatic precipitation	0.642[b]	-	205
Braintree #1	Electrostatic precipitation	0.435[b]	-	80.0[b]

[a] Dash indicates data not available in this form.

[b] Represents total inlet and outlet values.

Advances in particulate control technology for incinerators can decrease particulate emissions to the extent that compliance with federal regulations (0.08 gr/dscf at 12% CO_2) is possible. This is not to indicate, however, that any of the incinerators in Table 11 do not comply with applicable regulations. For example, EPA compliance tests were conducted by contractors in November 1977 and June 1978 at the Braintree incinerator [3]. At a refuse feed rate of 5-8 tons/hr, the emission rates were within state limitations of 0.10 gr/dscf at 12% CO_2 [3]. At optimum conditions, emission control systems for municipal incinerators can exhibit high levels of efficiency and be in accordance with federal and state regulations.

OTHER CRITERIA POLLUTANTS

Data are available in the literature for emissions of other criteria pollutants - sulfur oxides (SO_x), nitrogen oxides (NO_x), hydrocarbons (HC) - from incineration. Emission factors for these compound classes, as determined in the outlet gases from any particulate control device, and based on the total amount of feed material, are presented and discussed in the following sections.

Emission factors are determined by dividing the emission rate of individual pollutants (g/hr) by the total refuse feed rate (kg/hr). Emission rates are measures of the composition of the gas stream and stack flow rates of individual incinerators at the time the devices were tested. For example, a concentration of 50 ppm NO_x in incinerator exhaust gases of 571.1 m^3/min is equivalent to an emission rate of 3870 g/hr. This can be acquired by utilization of appropriate conversion factors, including the ideal gas law. Tables 12 through 15 present raw data for calculation of average emission factors for criteria pollutants, other than particulates, from Categories II and III and coal combustion. These data are summarized below in Tables 17 through 20.

TABLE 12. RAW DATA FOR CALCULATION OF AVERAGE EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM CATEGORY I [9][a]

Facility	SO_2, g/kg	NO_x, g/kg	Hydrocarbons, g/kg
Newport News, VA	0.590[b]	0.278[b]	0.025[b]
73rd St, NY, NY	0.023	0.366	-[c]
73rd St, NY, NY	0.288[b]	-[c]	0.306[b]
SW Brooklyn, NY	0.154	0.438	-[c]
Babylon, NY	0.322[b]	-[c]	-[c]
Miami County, OH	1.25	0.349	-[c]
Yokohama, Japan	0.542	-[c]	-[c]
Hamilton Ave, NY	0.176[b]	-[c]	0.0150[b]
Oceanside, NY	0.271[b]	-[c]	-[c]
Flushing, NY	0.221[b]	-[c]	0.225[b]
Average	0.38	0.36	0.14

[a] Emission factors calculated from pollutant concentrations assuming a refuse heating value of 14 MJ/kg and a stack gas flow rate of 7500 DSCF/10^6 Btu with an average moisture content of 19%.

[b] Represents average of test runs at facility.

[c] Data not given.

TABLE 13. RAW DATA FOR CALCULATION OF AVERAGE EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM CATEGORY II [3]

Run	Total feed rate, kg/hr	SO_2		NO_x		Hydrocarbons	
		g/hr	g/kg	g/hr	g/kg	g/hr	g/kg
1	4,700	4,420	0.94	3,870	0.82	298.6	0.06
2	4,600	4,191	0.90	3,825	0.80	221.0	0.05
3	4,100	4,923	1.20	3,282	0.82	285.4	0.07
Avg	4,467	4,511	1.0	3,659	0.82	268.3	0.06

[9] Jahnke, J. A., J. L. Cheney, R. Rollins and C. R. Fortune. A Research Study of Gaseous Emissions from a Municipal Incinerator. Journal of the Air Pollution Control Association, 27(8):747-753, 1977.

TABLE 14. RAW DATA FOR CALCULATION OF AVERAGE EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM CATEGORY III [4]

	SO_2, g/kg	NO_x, g/kg	Hydrocarbons, mg/kg
	38.86	1.47	3.30
	13.73	1.31	1.76
	44.62	2.02	3.69
	38.80	1.47	2.91
	5.88	2.57	1.31
	15.69	1.02	3.16
	24.93	1.06	1.17
	15.06	1.15	5.15
	13.30	1.30	2.83
	28.25	0.83	2.17
	6.69	1.77	1.17
	10.04	1.47	-
	-	1.61	-
Average	20.17	1.47	2.61

TABLE 15. RAW DATA FOR CALCULATION OF AVERAGE EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM COAL COMBUSTION [4]

	SO_2, g/kg	NO_x, g/kg	Hydrocarbons, mg/kg
	50.26	1.75	4.81
	22.14	2.16	1.77
	28.41	1.77	3.28
	52.44	2.94	1.97
	17.71	2.01	1.55
	19.93	2.35	1.77
	31.00	-	-
Average	31.70	2.10	2.52

Sulfur Oxides

Emission factors for sulfur oxides, reported as sulfur dioxide (SO_2), for all three categories and for coal combustion are given in Tables 12 through 15. The values for Category I were calculated from a table of stack gas concentrations [7] assuming an exhaust flow rate of 7,500 dry standard cubic feet per Btu of heating value of the feed material. Sulfur oxide emissions from Categories I and II are substantially lower than those from Category III or coal combustion. As shown in Table 16 the sulfur content of solid waste (Category II) is much less than that of coal or even coal mixed with up to 50 percent refuse by heat content (Category III). The data of Table 16 on the sulfur content of the various feed materials does in fact correlate well with the emission factors shown in Tables 17 through 20. Note that the average values on Tables 17 and 18 differ slightly from those calculated in Tables 12 and 13 because the former used each data point for each facility as a separate entry as opposed to using only the averages for each facility.

TABLE 16. TYPICAL SULFUR CONTENTS OF COMBUSTIBLE FRACTION OF FEED MATERIAL

Category	Sulfur content, % by weight (as S)
I	-[a]
II	0.18 - 0.31
III	1.41 - 4.84
Coal	3.06 - 6.66

[a]Data not available.

Nitrogen Oxides

Emissions of nitrogen oxides (NO_x) from combustion sources are due to nitrogen in the fuel or reactions between atmospheric nitrogen and oxygen at high temperatures. Generally, the nitrogen content of refuse is low. Therefore, differences in NO_x emissions between Categories I and II as compared to Category III or coal combustion are the result of differences in furnace operating temperature. Nitrogen oxide emissions from Category I or II are lower because the large amount of excess air--as much as 200%--needed to introduce the solid waste into the furnace reduces the combustion zone temperature by dilution. Normalization of NO_x emissions for percent excess air was beyond the scope of this project.

TABLE 17. EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM CATEGORY I [9]

Pollutant	Emission factor			
	Average		Range	
	g/kg	lb/ton	g/kg	lb/ton
Sulfur oxides (as SO_2)	0.33	0.66	0.02 - 0.92	0.05 - 1.8
Nitrogen oxides (as NO_2)	0.36	0.72	0.28 - 0.44	0.56 - 0.88
Hydrocarbons (as CH_4)	0.17	0.34	0.004 - 0.80	0.008 - 1.6

TABLE 18. EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM CATEGORY II [2, 3, 5]

Pollutant	Emission factor			
	Average		Range	
	g/kg	lb/ton	g/kg	lb/ton
Sulfur oxides (as SO_2)	1.0	2.0	0.11 - 3.2	0.21 - 6.4
Nitrogen oxides (as NO_2)	0.8	1.6	0.46 - 1.2	0.92 - 2.3
Hydrocarbons (as CH_4)	0.06	0.12	0.013 - 0.12	0.027 - 0.24

TABLE 19. EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM CATEGORY III [4, 6]

Pollutant	Emission factor			
	Average		Range	
	g/kg	lb/ton	g/kg	lb/ton
Sulfur oxides (as SO_2)	20	40	5.9 - 45	12 - 89
Nitrogen oxides (as NO_2)	1.5	2.9	0.8 - 2.6	1.7 - 5.1
Hydrocarbons (as CH_4)	0.003	0.005	0.001 - 0.005	0.002 - 0.01

TABLE 20. EMISSION FACTORS FOR OTHER CRITERIA POLLUTANTS FROM COAL COMBUSTION[a] [4, 6]

Pollutant	Emission factor			
	Average		Range	
	g/kg	lb/ton	g/kg	lb/ton
Sulfur oxides (as SO_2)	32	64	18 - 52	35 - 104
Nitrogen oxides (as NO_2)	2.1	4.2	1.7 - 2.9	3.4 - 5.9
Hydrocarbons (as CH_4)	0.003	0.005	0.002 - 0.005	0.003 - 0.01

[a]Data are for coal combustion in a unit suited to cofiring of refuse-derived and fossil fuels.

Hydrocarbons

When any combustible solid, such as coal or refuse, is heated in the absence of oxygen, combustible gases are evolved. For example, unburned material on top of a grate-type fuel bed will be heated by combustion gases passing through from below, and volatile hydrocarbons will be released. In the case of incineration, a lesser mass of hydrocarbons is emitted than any other criteria pollutant, as can be seen by inspection of Tables 5 through 7 and 17 through 19. The larger amount of hydrocarbons emitted from mass-fired incineration relative to co-firing or coal combustion may be due to the combustion of cellulose fiber present as wood chips or paper.

SECTION 4

EMISSIONS OF NONCRITERIA POLLUTANTS

HYDROGEN CHLORIDE

Flue gases from solid waste combustion contain hydrogen chloride, a by-product of the combustion of polyvinyl chloride and other chlorinated plastics found in the feed. Raw data used in calculation of hydrogen chloride emission factors for the three categories discussed herein, as well as for coal combustion, are presented in Tables 21 and 22 and then summarized in Table 23. Such emissions from the combustion of mass-fired or co-fired refuse are greater than those for coal alone. However, no generalizations can be made about the magnitude of the deviation because several factors may influence hydrogen chloride emissions. For instance, hydrogen chloride may be absorbed by the alkaline constituents of ash in the combustion chamber. Alternatively, particulate control techniques that involve water sprays may be as much as 80 to 95 percent effective on the soluble chloride gas. The fly ash removed by electrostatic precipitation may absorb some hydrogen chloride.

TRACE ELEMENTS

Certain chemical compounds of the following trace elements are potentially toxic to people if deposited in their lungs: antimony, arsenic, cadmium, chromium, lead, nickel, selenium, and tin. It is possible for these toxic substances to be released from the incineration process. Tables 24 through 27 comprise a summary of available information on the trace element content of particulates emitted from incineration, including data taken before and after pollution control devices for Categories II and III and for coal combustion.

Other investigators have determined that Category I incinerators operating in different geographic regions of the United States and serving different types of communities have similar trace element emissions. Also, no significant day-to-day or seasonal changes in particulate composition were observed at any one site.

TABLE 21. RAW DATA FOR CALCULATION OF AVERAGE HYDROGEN CHLORIDE EMISSION FACTORS FROM CATEGORY I [9][b]

Facility	NO_x, g/kg
Newport News, VA	0.142
73rd St, NY, NY	0.4[a]
S.W. Brooklyn, NY	0.365
Babylon, NY	1.31[a]
Yokahama, Japan	1.59
Salford, England	1.28
Hamilton Ave, NY	0.38[a]
Oceanside, NY	0.59[a]
Flushing, NY	0.22[a]
Average	0.66

[a] Represents average of test runs at facility.

[b] Emission factors calculated from pollutant concentrations assuming a refuse heating value of 14 MJ/kg and a stack gas flow rate of 7500 dscf/10^6 Btu with an average moisture content of 19%.

TABLE 22. RAW DATA FOR CALCULATION OF AVERAGE HYDROGEN CHLORIDE EMISSION FACTORS FROM CATEGORY III AND COAL COMBUSTION [4, 6]

	Category III, g/kg	Coal combustion, g/kg
	1.32	0.28
	1.17	0.14
	1.13	0.48
	1.20	0.15
	0.86	0.14
	1.88	0.21
	1.61	0.09
	2.33	
	1.66	
	1.68	
	1.47	
	1.84	
	2.12	
Average	1.60	0.21

TABLE 23. HYDROGEN CHLORIDE EMISSION FACTORS[a]

	Emission factor			
	Average		Range	
Category	g/kg	lb/ton	g/kg	lb/ton
I	0.7	1.4	0.14 - 1.6	0.28 - 3.2
II	-[b]	-[b]	-[b]	-[b]
III	1.6	3.2	0.9 - 2.3	1.7 - 4.7
Coal	0.2	0.4	0.90 - 0.5	0.2 - 1.0

[a]Data represent values downstream of any particulate control device.

[b]Data not available.

TABLE 24. CONCENTRATIONS OF TRACE ELEMENTS IN PARTICULATE EMISSIONS FROM CATEGORY I [9]

Element	Concentration,[a] μg/g or 10^{-6} lb/lb
Antimony	610 - 12,600
Arsenic	80 - 510
Barium	40 - 1,700
Bromine	320 - 6,700
Cadmium	520 - 2,300
Chlorine	99,000 - 330,000
Chromium	70 - 1,800
Cobalt	2 - 30
Copper	970 - 6,800
Iron	1,700 - 18,000
Lead	50,000 - 155,000
Manganese	170 - 5,700
Nickel	40 - 440
Selenium	10 - 120
Silver	40 - 2,000
Tin	8,500 - 15,100
Zinc	47,000 - 240,000

[a] Data are for trace element content of particulates downstream of any pollution control device; i.e., controlled emissions.

TABLE 25. CONCENTRATIONS OF TRACE ELEMENTS IN PARTICULATE EMISSIONS FROM CATEGORY II [2, 3, 5]

Element	Concentration, μg/g or 10^{-6} lb/lb	
	Uncontrolled	Controlled
Antimony	260 - 620	460 - 1,000
Arsenic	50 - 70	50 - 100
Barium	270 - 540	270 - 540
Bromine	420 - 2,400	350 - 1,200
Cadmium	380 - 820	670 - 1,150
Chlorine	>10,000	>10,000
Chromium	50 - 560	130 - 260
Cobalt	10 - 100	5 - 50
Copper	420 - 590	620 - 800
Iron	970 - 1,090	2,000 - 2,130
Lead	11,600 - 17,500	18,100 - 34,200
Manganese	420 - 1,400	140 - 490
Nickel	-[a]	-[a]
Selenium	<90	<30
Silver	110 - 200	50 - 110
Tin	2,600 - 5,000	1,400 - 5,000
Zinc	>10,000	>10,000

[a] Data not available.

TABLE 26. CONCENTRATIONS OF TRACE ELEMENTS IN PARTICULATE EMISSIONS FROM CATEGORY III [4, 6]

Element	Concentration, μg/g or 10^{-6} lb/lb					
	Uncontrolled			Controlled		
Antimony	0.4	-	10	2	-	180
Arsenic	20	-	80	140	-	740
Barium		-[a]			-[a]	
Bromine		-[a]			-[a]	
Cadmium	0.3	-	1.4	0.2	-	10
Chlorine		-[a]			-[a]	
Chromium	5	-	20	60	-	100
Cobalt	0.6	-	2.0	4	-	40
Copper	10	-	50	50	-	280
Iron	700	-	2,410	6,940	-	17,300
Lead	1,220	-	2,930	4,470	-	18,400
Manganese	10	-	20	110	-	240
Nickel	3	-	20	20	-	190
Selenium	10	-	40	20	-	430
Silver		-[a]			-[a]	
Tin	50	-	150	260	-	870
Zinc	860	-	3,770	4,360	-	17,200

[a]Data not available.

TABLE 27. CONCENTRATIONS OF TRACE ELEMENTS IN PARTICULATES EMITTED FROM COAL COMBUSTION [4, 6]

Element	Concentration, μg/g or 10^{-6} lb/lb					
	Uncontrolled			Controlled		
Antimony	7	-	20	10	-	150
Arsenic	20	-	120	20	-	680
Barium		-[a]			-[a]	
Bromine		-[a]			-[a]	
Cadmium	0.6	-	1.0	2	-	8
Chlorine		-[a]			-[a]	
Chromium	6	-	8	30	-	40
Cobalt	0.4	-	1.5	3	-	30
Copper	6	-	7	30	-	40
Iron	2,350	-	2,800	13,200	-	18,200
Lead	340	-	380	1,050	-	1,790
Manganese	20	-	40	100	-	140
Nickel	6	-	20	30	-	40
Selenium	10	-	50	30	-	40
Silver		-[a]			-[a]	
Tin	20	-	30	30	-	270
Zinc	180	-	560	910	-	3,340

[a]Data not available.

The major constituents of controlled particulate emissions from Category I incineration, in approximate decreasing order by dominant presence of the first three of these elements is due to the abundance of the elements in the fuel as fired. This phenomenon is best shown for Category II, as can be seen from the relatively large concentrations of chlorine, lead, and zinc shown in Table 25.

Other significant observations can be drawn from the data for Category II. First, the maximum concentrations of all trace elements in the controlled particulate emissions from Category II are less than the corresponding values for Category I. Category II incinerators extract more heat energy from the exhaust stream than Category I incinerators. This added heat recovery may be sufficient to cool the stack gases to the point that volatile elements can condense and therefore be more efficiently removed by the particulate control devices.

The data for Category II also demonstrate the selective fractionation of volatile elements into fine particles, those most likely to escape any attempted control. Elements previously shown to occur primarily in the fine-particle regime, that is, less than two micrometers in diameter, are not collected by the control device; some of these elements are antimony, cadmium, and lead. Since the large particles are removed, the ratio of the weight of these elements to the total mass is increased. This increase in concentration has potentially negative implications for human health effects because fine particulates can more easily reach the lower respiratory tract.

Element fractionation discussed above for Category II is also evident in the data for Category III and for coal combustion. In the latter two cases, the effect can also be readily seen for three more volatile elements: arsenic, selenium, and zinc.

Another point of interest is a comparison of the trace element contents of uncontrolled particulate emissions for the three categories and for coal combustion. The composition of particulates from Category III, for which the fuel is a mixture of solid waste and coal, and from coal combustion are approximately the same, with the possible exceptions of lead and zinc, which appear to a greater extent for Category III. This difference must be qualified, because the gas-phase emissions of these two elements, both of which are volatile, are not available.

Likewise, the apparently greater emissions from Category II relative to Category III must also be evaluated more closely. For example, consider the case for lead. The concentrations in uncontrolled particulates for Categories II and III are 11,600 to 17,500 µg/g and 1,220 to 2,830 µg/g, respectively; these values differ by a factor of four to fourteen, depending upon

which values are compared. From Table 9, the uncontrolled particulate emission factors for Categories II and III are 6.9 to 23 g/kg and 43 to 85 g/kg, respectively; these values differ by a factor of two to twelve, but in the opposite direction from those described above for trace element concentration. Therefore, when compared on the basis of micrograms emitted per kilogram of material burned, trace elements emissions from the mass-fired incineration of solid waste with heat recovery are not significantly different from those from the combustion of refuse co-fired with coal.

POLYNUCLEAR AROMATIC HYDROCARBONS AND POLYCHLORINATED BIPHENYLS

Polynuclear aromatic hydrocarbons are formed by the incomplete combustion of solid waste or other fuel material. Gases leaving an incinerator may contain polynuclear hydrocarbons both in the vapor phase and adsorbed on particulates. Emission factors for these compounds in stack gases downstream of any particulate control device are given in Tables 28 and 29 on the basis of mass emitted per mass of total material fed.

For Category I, more polynuclear hydrocarbons are emitted from small-sized furnaces because of poor combustion conditions relative to those in larger units. However, regardless of incinerator size, differing emission levels may be found during startup, normal operation, and shutdown. Wet scrubbing devices for particulate control at Category I incinerators have proven highly effective in reducing polynuclear hydrocarbon emissions; in one case, benzo(a)pyrene emissions were reduced by more than 95%.

Data on polynuclear hydrocarbon emissions from Category II is extremely limited. At one site, six compounds were observed in the gas phase: acenaphthylene, anthracene, fluoranthene, fluorene, phenanthrene, and pyrene. Fly ash collected by electrostatic precipiation contained acenaphthylene, anthracene, phenanthrene, and pyrene; however, all levels measured in both sample sets were below the range of reliable quantitative analysis.

Data on polynuclear aromatic hydrocarbon emissions from Category III are shown in Table 29. In addition, benzo(a)pyrene, benzo(e)pyrene, and perylene have been detected in particulates, but the amounts were not reported. Data on polynuclear hydrocarbon emissions from the combustion of coal only in a Category III boiler were not available.

Polychlorinated biphenyls could not be detected in particulates from either Category II or III or in vapor samples from Category III.

TABLE 28. EMISSION FACTORS FOR POLYNUCLEAR AROMATIC HYDROCARBONS FROM CATEGORY I

Compound(s)	Emission factor	
	µg/kg	10^{-6} lb/ton
Benzo(a)anthracene and chrysene	3.1[a]	6.2[a]
Benzo(b)fluoranthene, benzo(j)fluoranthene, and benzo(k)fluoranthene	1.4[a]	2.8[a]
Benzo(ghi)perylene	1.4 - 1.8	2.8 - 3.6
Benzo(a)pyrene and benzo(e)pyrene	0.08 - 1.5	0.16 - 2.9
Coronene	0.17 - 1.4	0.34 - 2.8
Fluoranthene	2.5 - 7.3	5.0 - 15
Indeno(1,2,3-cd)pyrene	0.77[a]	1.5[a]
Perylene	0.77[a]	1.5[a]
Pyrene	4.6 - 6.8	9.2 - 14

[a]Only one value reported.

TABLE 29. EMISSION FACTORS FOR POLYNUCLEAR AROMATIC HYDROCARBONS FROM CATEGORY III [4, 6]

Compound(s)	Emission factor	
	µg/kg	10^{-6} lb/ton
Benzo(a)pyrene, benzo(e)pyrene, and perylene	0.76	1.5
1,2-Benzofluorene and 2,3-benzofluorene	0.57	1.1
Fluoranthene	1.2	2.5
Fluorene	0.38	0.76
Pyrene	0.38	0.76

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SECTION 4

COMPARISON WITH AP-42 FACTORS

The U. S. Environmental Protection Agency's "Compilation of Air Pollutant Emission Factors," or Publication No. AP-42, has long been used as source material for data on emissions from fuel combustion, incineration, evaporation losses, and miscellaneous other sources. Tables 30 and 31 compare the emission factors, in metric and English units, respectively, for uncontrolled criteria pollutants from municipal, industrial, and commercial incinerators as reported in AP-42, and for Categories I, II, and III and coal combustion as determined in this study. The numerical values in Tables 30 and 31 were calculated using total feed material as the basis.

For particulates, sulfur oxides, and nitrogen oxides, values given in AP-42 and those reported herein for Categories I and II, the most directly comparable combustion processes, overlap. The emission factors for hydrocarbons given in AP-42 are significantly higher than those found during the current investigation. This may be so because the most recent data source cited in the AP-42 review of refuse incineration was published in June 1971, whereas this report is based on information released as recently as December 1978. During that time, changes may have occurred in refuse composition, incinerator operation, or capabilities of sampling and analysis techniques used to determine emissions. Any of these changes could result in the emission factor difference.

TABLE 30. COMPARISON OF EMISSION FACTORS FOR UNCONTROLLED CRITERIA POLLUTANTS FROM INCINERATION AS REPORTED IN AP-42 AND THIS STUDY (metric units) [1-7, 9]

Category	Emission factor, g/kg			
	Particulates	Sulfur oxides	Nitrogen oxides	Hydrocarbons
Municipal, industrial, and commercial incineration (AP-42)	3.5 - 15	1.25	1 - 1.5	0.75 - 7.5
I	11 - 27	0.02 - 0.92	0.28 - 0.44	0.004 - 0.80
II	6.9 - 23	0.11 - 3.2	0.46 - 1.2	0.013 - 0.12
III	43 - 85	5.9 - 45	0.8 - 2.6	0.001 - 0.005
Coal combustion	40 - 90	18 - 52	1.7 - 2.9	0.002 - 0.005

TABLE 31. COMPARISON OF EMISSION FACTORS FOR UNCONTROLLED CRITERIA POLLUTANTS FROM INCINERATION AS REPORTED IN AP-42 AND THIS STUDY (English units) [1-7, 9]

Category	Emission factor, lb/ton			
	Particulates	Sulfur oxides	Nitrogen oxides	Hydrocarbons
Municipal, industrial, and commercial incineration (AP-42)	7 - 30	2.5	2 - 3	1.5 - 15
I	22 - 54	0.05 - 1.8	0.56 - 0.88	0.008 - 1.6
II	14 - 45	0.21 - 6.4	0.92 - 2.3	0.027 - 0.24
III	85 - 171	12 - 89	1.7 - 5.1	0.002 - 0.01
Coal combustion	80 - 179	35 - 104	3.4 - 5.9	0.003 - 0.01

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